One- to Two-Month oscillations in SSM 1 Surface Wind Speed

in the Western Tropical Pacific Ocean

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Abstract. The 1(1-I)] wind sped over the ocean can be estimated from microwave brightness temperature measurements recorded by the Special Sensor Microwave Imager (SSM 1) instrument mounted on a polar-orbiting spacecraft. 1 kmr-year(1988 -1 991) time series of average daily 10 x J" SSh41 wind speeds were. analyzed at selected sites in the western tropical Pacific Ocean. One- to two-month period wind speed oscillations with amplitudes statistically significant at the 95% confidence level were observe.(1 near Kanton, iniwetok, Guam, and Truk. This is the first report of such an oscillation in SSM I wind speeds.

Introduction

The first Special Sensor Microwave Imager (SSh41) instrument was launched on a polar-orbit ing 1)efense Meteorological Satellite Program (DMSP) spacecraft in July 1987. A second and third SSh4 I were launched in 1)ecember 1990 and November 1991. Algorithms translate SSMI measurements of polarized microwave radiation into atmospheric variables, including wind speed at 1 O-m height over the ocean.

The objective of this study is to determine whether SSM I wind speeds in the tropical Pacific contain evidence of the 40- to 50-clay period Madden-Julian Oscillation (MJO), which was first discovered by Madden and Julian[1971, 1972; see also Madden and Julian [1994] for a review]. Their studies revealed a spectral peak centered around periods of 40 - 50 days in pressure, renal wind, and temperature data. The MJO occurs throughout the tropical upper troposphere, but in the lower troposphere it is strongest in the western Pacific. The MJO originates over the warm water of the eastern Indian Ocean and western Pacific Ocean, and moves eastward at about 5 m s'f. The MJO is representative of equatorial trapped Kelvin waves created by convective disturbances between about 60°E and 160')1 :.

Data, nstrumentation and Analysis

The SSM I is a 7-channel, 4-frequency, linearly polarized, passive microwave radiometer. The intensity of microwave radiation emitted at the ocean surface is affected by sea surface roughness, which is corrc.late.d with surface wind speed. Remote Sensing Systems (RSS) of Santa Rosa, California, used the Wentz [1989, 1992] procedure to process 37-GHz vertical - and horizontally-polarized brightness temperatures into 10-m height wind speeds. The model function relating wind speed to electromagnetic radiance was considered invalid within 1 00 km of land and 200 km of sea ice edge, and when the total liquid watt] content in the atmosphere was greater than 0.25 kg m^{-2} because in each case there would be a marked change in radiative emission.

The RSS-derived SSMI wind speeds occurred in non-overlapping areas of 25 km x 25 kin, which were arrayed across the approximate 140()-kIII swath width. Geographical coordinates correspond to the center of each 25-km x 25-km region. A daily arithmetic mean wind sped was computed at the Jet Propulsion 1 .aboratory for each 1/3" x 1 /3° area. Most 1/3" x 1/3° areas contained two or three SSMI wind measurements per day. The 1/3° x 1 /3° area is the pixel size of a number of satellite-derived data products, including monthly mean SSh41 wind speed and associated sampling distribution, published in a series of annual atlases [e. g., 1 lalpern *et al.*, 1 993]. Average daily 1 o x 1° wind speeds were computed at Iowa State University (ISU) when five or more of the nine 1/3° x 1/3° elements contained data. 1 Data gaps were filled with a time and space weighted averaging scheme employing daily 1° x 10 values. A data gap longer than 20 days was not find.

The accuracy of SSh4 I wind speeds in the tropical Pacific Ocean has been determined by comparison with moored-buoy wind measurements (referenced to 10-m height) at about twenty sites. The root-mean-square (rms) difference and mean difference between mean daily buoy and 2/3" x 2/3° SSMI wind speeds in the tropical Pacific during 1988 and 1989 were 1.5 and **0.2. m s 1,** respectively; the correlation coefficient was 0.75. For monthly mean wind speeds, the. rms difference decreased to 0.9 m s^{-1} and the correlation coefficient increased to 0.81 [1 lalpern, 1993].

Although the SSM 1 data set began in July 1987 and continues to the present, the 13 January 1988 to 18 December 1991 time interval was chosen. A 40-day data gap had occurred immediately prior to 13 January 1988. The SSh41 data available after 18 December 1991 were recorded with a different SSh41 on a different DMSP space.craf(, and differences between the two SSMI data sets [Halpern and Wentz, 1994] were considered too large to create a composite 2-satellite data set.

In the spectral analysis technique employed at ISU, a linear least-squares fit of the form At -t W was performed on each time series of daily 1 c. x 1" wind speeds, where A, t and W are the slope of [he. linear trend, t is time and W is the wind sped at t = o, respectively. The linear trend was removed to create the time series of the wind speed fluctuations W'_j. The standard deviation, o, of the detrended time series was calculated. A new time Series, $W'_j o^1$, was constructed, which represented the. detrended series with each wind sped expressed in terms of o.

A cosine taper was applied to the beginning and end 10% of the. time series to reduce spectral leakage. Each series was then spectrally analyzed by fast Fourier transformation and the power P_k was calculated for each Fourier harmonic k, according to the definition $P_k = (1/2.)(C_k^2 -t S_k^2)$, where C_k and S_k are the kth Fourier cosine and sine coefficients. The $\{P_1, ..., P_{N/2}\}$ values formal the periodogram or power spectral density with two degrees of freedom (1 DOF). In the present study, 5° x 5° regions were arbitrarily chosen adjacent to five sites in the tropical Pacific (Table 1), where Madden and Julian [1971, 1972] found evidence of 1- to 2-month oscillations. Because SSM I wind speeds do not exist for land locations, no SSMI series could be obtained for the actual locations employed by Madden and Julian [1971, 1972]. The ensemble of twemty-five (maximum) periodograms, each associated with a 1" x 1° area, was averaged. At Iniwetok and Yap, the ensemble consisted of 24 elements; at other sites the number of 10 x 10 areas was 2.0. Individual periodograms within each 5° x 5° area were not independent bc.cause the horizontal scale of the MJO was much larger than 5°. The 5° x 5° ensemble-averaged periodogram was smoothed with a 7-point running mean to yield power spectral density estimates with 14 DOF.

The background power spectral density B_k **was** determined subjectively, and hand-sketched onto the spectral density diagram. The sif,l~al-lo-noise ratio R_k is equal to P_k/B_k for the kth frequency, and R_k is used to determine the statistical significance of a spectral peak.

'1'0 test whether a SSMI wind sped spectral density peak at 1- to ?-month periods, which has previously been revealed in a variety of data to correspond to an atmospheric phenomenon [Madden and Julian, 1994], is statistically significant (and, therefore, may represent an atmospheric circulation phenomenon), we make the null hypothesis that any such peak is due. only to random fluctuations. The level of statistical significance used throughout the paper is 95%. If the hypothesis is rejected, the spectral peak will be taken to be statistically significant. The hypothesis is rejected if& exceeds a critical magnitude M_c (= 1.7) that depends on the DOF and that is determined from the chi-square distribution. Following Madden and Julian [1971], we call this an "a priori" statistical test. If we examine only this spectral band, a R_k exceeding 1.7 establishes the statistical existence of a SSMI wind speed oscillation.

Results

The 4-year mean and avc.rage standard deviation of the daily $5° \times 5°$ SSMI wind speeds at the five site.s were 6.5 and 2.2 m s^{-1}, respectively. Not much variation of mean and standard deviation values occurred between the sites (Table 1).

A statistically significant spectral peak at 1- to ?-month periods was measured at Kanton (Figure 1) and at 1 iniwetok, Guam and Truk (Figure 2). No such statist ical y significant spectral peak was evident in the SSM 1 wind speeds al Yap, in contrast to the MJO observed by Madden and Julian [1972]. The amplitude of the oscillation at Truk, although statistically significant, was not as prominent as at the other sites.

The 1 2-day period spectral peak at Eniwetok is not considered to be statistically significant., even though the associated R_k was greater than M_c. To ensure that (here is only a 5% chance of a spectral peak caused by random fluctuations being i ncorrectly interpreted to be represent at ive of

atmospheric phenomena, the. confidence level must be increased to 99,95%, This "a posteriori" statistical significant test [Madden and Julian, 1971] is an after-the-fact test. For 14 IX)] I', $M_c = 2.7$, indicating that all spectral peaks other than those associated with 1- to 2- month periods, including, the 12-day peak at Eniwetok and the 7- to 9-day peak at Kanton, were not considered statistically significant. The higher frequency spectral peaks perhaps arise from intermittent bands of convection which pass every week or so, but did not occur uniformly enough over the 4 years to be statistically significant at 14 1X)]'. Note, however, that convection bands may have smaller sc.ales than the. 5° x 5° box size, and thus larger IX)]:. A proper method of assigning the statistical significance, beyond the. scope of the. present paper, is through the use of Monte Carlo field statistic testing [Stanford and Ziemke, 1994].

At Kanton, the strong oscillation is well defined in the unfiltered time series of daily mean 1° x 1 c.SSMI wind speeds (Figure 3). The amplitude of the 30- to 60-day period oscillation at Kanton varies throughout the time record. As can be seen in Figure 3, the MJO signal comprises a substantial portion of the record-length standard deviation (1.7 m s^{-1}, 'J'able 1), with typical amplitudes of 1 m s^{-1} and occasionally exceeding 2 ms^{-1}. The 30- to 60-day band-pass filtered time series (Figure 3) revealed a weaker amplitude in 1988 during La Niña than that in 1991 during El Niño, in accordance with the increased number and intensity of westerly wind bursts that are associated with the MJO and with the onset of El Niño [Luther et al., 1983]. A westerly wind burst in the western Pacific creates a downwelling Kelvin wave pulse in the ocean to deepen the thermocline and raise. sea level in the eastern Pacific.

in summary, evidence was presented for 1- to 2-month oscillations in SSMI wind speeds in the western tropical Pacific. This is the first report **of the.** phenomenon with SSM 1 wind speeds. Hong and Kim [1994] found evidence of the MJO in SSM 1 rainfall data. 'J'bus, SSMI data can be used to describe several features of the. MJO osci 1 lation over vast regions of ocean without islands.

References

Halpern, D., Validation of Special Sensor Microwave Imager monthly-mean wind sped from July 1987 to December 1989. *IEEE Trans. Geosci. Remote Sens.*, *31*, 692-699, 1993.

Halpern, D., and F. Wentz, On the problem of measuring interannual wind speed variations using SSMI data. *Geophys. Res. Lett.*, *21*, 193-196, 1994.

Halpern, D., W. Knauss, 0. Brown, and F. Wentz, An atlas of monthly mean distributions of SSM/I surface wind speed, ARGOS buoy drift, AVHRR/2 sea surface temperature, and ECMWF surface wind components during 1990. JPL Publication 93-1, Jet Propulsion Laboratory, Pasadena, 111 pp.

Hong, Y., and H.-S. Lim, Evidence for low-frequency waves of tropical rainfall inferred from microwave brightness temperature. *Mon.Wea.Rev.*, *122*, 1364-1370, 1994.

Luther, D. S., D.E. Harrison, and R. A. Knox, Zonal winds in the central Pacific and El Niño. *Science*, 222, 327-330, 1983.

Madden, R. A., and P. R. Julian, Observations of the 40-50-day tropical oscillation -- A review. *Mon.Wea.Rev.*, 122, 814-837, 1994.

Madden, R. A., and P. R. Julian, Description of global-scale circulation cells in the tropics with a 40-50 day period, *J.Atmos.Sci.*, 29, 1109-1111, 1972.

Madden, R. A., and P. R. Julian, Detection of a 40-50 day oscillation in the renal wind in the tropical Pacific. *J.Atmos.Sci.*, *28*, 702-708, 1971.

Stanford, J. L., and J. R. Ziemke, Field (map) statistics. In: *Statistical Methods for Physical Science*, J. L. Stanford and S. B. Vardeman, editors, Academic Press, in press, 1994.

Wentz, 1 ., Measurement of oceanic wind vector using satellite microwave radiometers. *IEEE Trans.Geosci.Remote Sens., 30, 960-972, 1992.*

Wentz, F., User's manual SSMI geophysical tapes. Technical Report 060989, 16 pp., Remote Sensing Systems, Santa Rosa, Calif.,1989.

Table *1.* Location of 5° x 5° regions corresponding to five islands in the western tropical Pacific Ocean, and mean and standard deviation (Std Dev) of daily average SSM1 wind speeds during 1988 - 1991

Island	Location	Location of Northwest Corner of 5° x 5" Region	SSMI Wind Speed (m s^{-1}) Mean	Std Dev
Kant on	?.8°s, 171.7°W	0°, 175°w	7.3	1.7
Eniwetok	11.4°N, 162.4°E	14°N, 160°E	7.3	2.,1
Guam	13.6°N, 144.8°E	16°N, 142."1	6.2	2.3
Yap	9.5°N, 138.2°E	12°N, 136°E	5.7	2.4
Truk	7.5°N, 151.8°E	10"N, 149°E	6.2	2.3

1 Figure 1. Power spectral density (relative units) versus period (in days) for 1-day, 5° x 5° average SSMI wind speeds at IO-m height near Kanton island (2..8"S, 171.7°W) during 1988- 1991. The northwest corner of the 5° square is locate.d at 0°, 175"W. The spectrum was computed from an ensemble average of 20 spectra associated with 1 -day, 10 x 10 SSMI wind speed time series within the 5° x 5° area. Spectral densities were. averaged over 7 periodogram values and have 14 degrees of freedom. The red-noise background values (thin-dash line) was subjectively evaluated. The 95% confidence level of spectral densit ics (thick-dash 1 inc) was computed from the chi-square distribution. The 30- to 60-day spectral peak is statistically significant at the 95% confidence level.

1 Figure 2. Power spectral density (relative units) versus period (in days) for 1-clay, 5° x 5° average SSM 1 wind speeds at 1 O-m height near four central Pacific islands during 1988-1991:1 iniwetok (11.4°N, 162.4°E), Kanton (2.8°S, 171.7°W), Guam (13.6°N, 144.8°E), Truk (7.5°N, 151.8°E). 1 Each spectrum was computed from an ensemble average of at least 20 spectra associated with 1-clay, 10 x 10 SSMI wind speed time series within the 5° x 5° area. Spectral density curves for Iniwetok, Kanton and Guam are displaced vertically for clarity, with zero spectral density indicated by a short horizont al 1 inc (above periods of 5 to 7 clays). All four spectra exhibit 1- to 2-month oscillations that arc 95% statistically significant, with the minimum amplitude occurring at Truk.

Figure 3. Time series of daily 1° x 10 SSMI wind speeds recorded immediately south of Kanton. (Upper Curve) Unfiltered wind speed (m s-]) fluctuations about the 7.2 m s^{-1} mean wind speed (clashed line). Evidence for a 30-to 60-day fluctuation is discerned throughout the 4-year record. (Lower Curve) Same as upper curve but digitally band-pass filtered with half amplitude at 30- and 60-day periods.
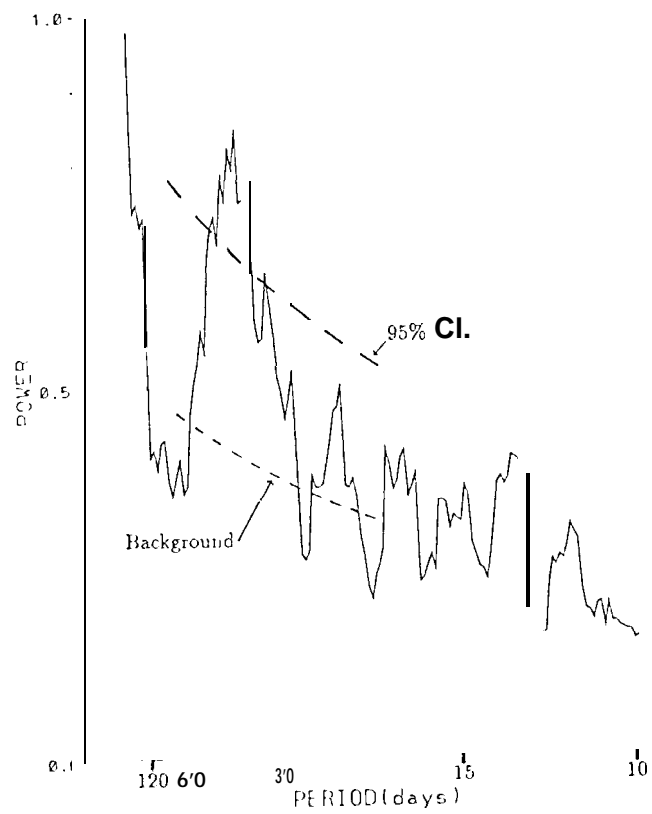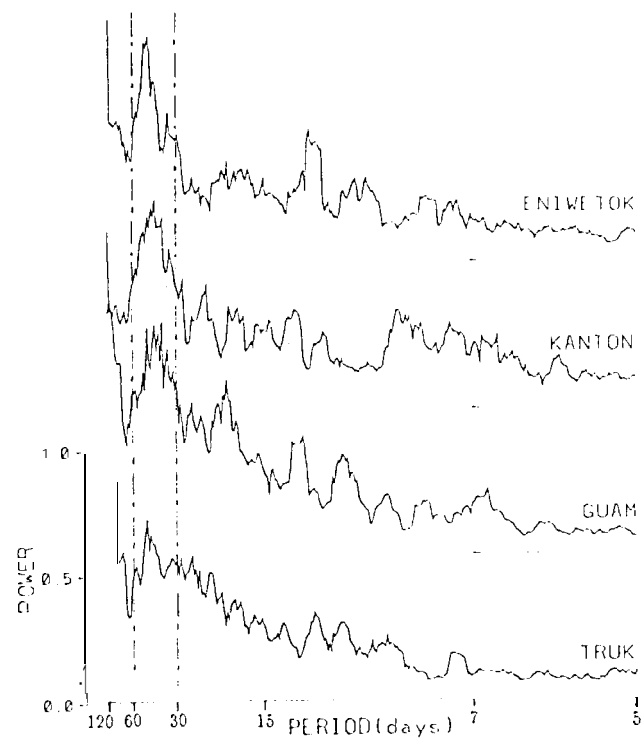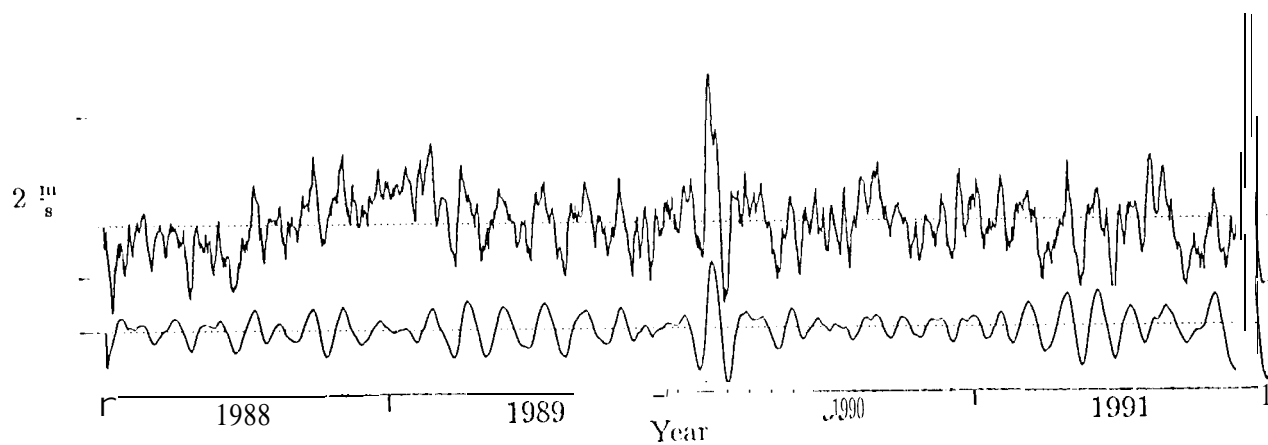
Figure 1

ENIWETOK

KANTON

GUAM

TRUK

POWER

1.0

0.5

0.0

120 60   30   15 PERIOD(days)   7   5

Figure 2

Figure 3